Active Galactic Nuclei (AGN) as an Alternate Probe of the Cosmic Expansion History

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As a Science Challenge for the Astrophysics Roadmap, we propose that the potential of AGN as distance indicators be fully explored over the next decades for the benefit of cosmology and astronomy in general.

One of the strongest tests of our physical understanding of the Universe is the ability to repeat an experiment using independent methods, and in doing so, achieve the same result. A scientific breakthrough is rarely embraced until such an experiment produces the same outcome when repeated and then verified independently. Accurate distance measurements provide crucial mapping of the Universe and its rate of expansion. Supernova (SN) Ia distances (Riess et al. 1998, AJ, 116, 1009; Perlmutter et al. 1999, ApJ, 517, 656) led to the discovery of its accelerated expansion and the existence of dark energy, which constitutes ~70% of the energy budget. A range of complementary methods are now employed in an attempt to understand its nature, including SNe Ia, Baryonic Acoustic Oscillations (BAOs), weak lensing, and the Cosmic Microwave Background (CMB), but if we are to understand dark energy, we need independent measurements that probe the same scales as the former methods and beyond. We propose to explore the potential of a new complementary distance indicator using AGN that works similarly to SNe Ia but can extend to redshifts above z ~2.

AGN distance indicator: The size of the central Hβ emitting region, R(Hβ), is shown empirically to scale with the nuclear continuum luminosity L: $R \sim L^{\alpha}$ with $\alpha \approx 0.5$ (e.g., Bentz et al. 2013, arXiv1303.1742). This relation is tight enough (scatter ~0.13 dex) to hold great promise as a standard candle: by measuring the broad-line region size R(Hβ) with reverberation mapping, we can infer the luminosity distance from the observed AGN flux (Watson et al. 2011, ApJ, 740, L49). Indeed, cosmic distances inferred from R(Hβ) show good consistency with the actual distances (Figure, left). The large intrinsic brightness of AGN enables a mapping of the Universe at high z, where w_a, the time derivative of the dark energy equation of state, is best probed. Probing high redshifts with AGN provides improved constraints over SN Ia (Figure, middle); SNe are rarely detected above z~1.4 (Suzuki et al. 2011, ApJ, 746, 85). Regardless of future advances that may change this, the AGN method will remain complementary to SNe, BAOs, the CMB, and weak lensing, as it is an *entirely independent method.* Also, the physics underlying the $R - L$ relation is well understood. To optimize this relation for distance measurements, the current scatter of ~0.33mag in the distance modulus can be reduced to ~0.2mag by relatively straightforward efforts. With similarly dedicated efforts as those applied to SNe, the AGN method can be sufficiently improved and calibrated to enable its application.

With A. King, T. Davis (U. Queensland) and D. Watson (Niels Bohr), we use simulations to determine the optimal experiment design for the AGN method to provide key constraints on the cosmological parameters. So far, the study shows that AGN distances can help yield tight constraints on w. By combining the methods of SNe, BAO, CMB, and AGN distances measured up to z~3, we can increase the combined Dark Energy Figure of Merit by a factor of 2 (Figure, right). In fact, AGN can reach large enough distances to provide the possibility of probing the onset of accelerated expansion and, in principle, provide the opportunity to discover new physics. Thus, given the importance of cosmic expansion and the nature of dark energy, we cannot afford *not* to explore and to calibrate this promising tool for measuring distances at large cosmic scales.

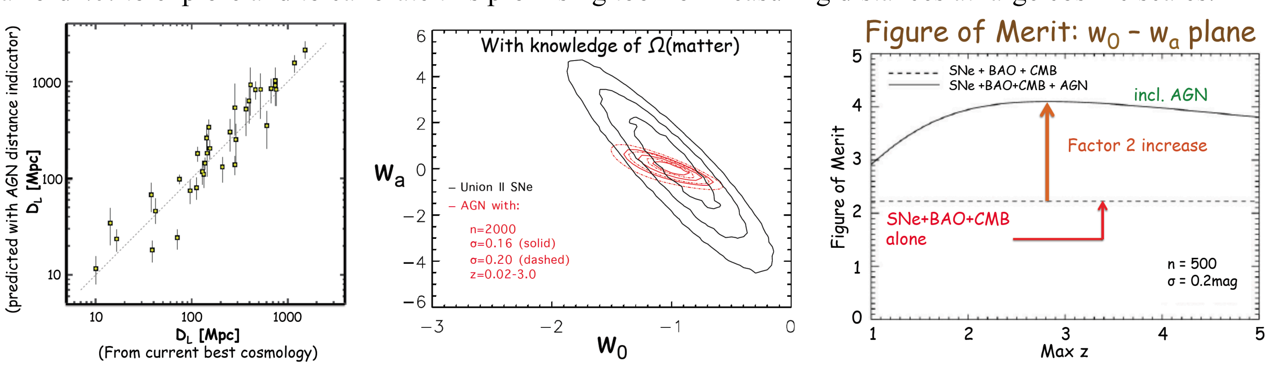

Figure: *Left:* AGN distances (currently anchored by a direct distance measure to one AGN; Watson et al. 2011) are consistent with the best current cosmology (dotted curve; not a fit). *Middle*: Simulated constraints from AGN compared with SNe Ia (Union II sample, Amanullah et al. 2010, ApJ, 716, 712): the different angles of the AGN and SNe contours show the effect of probing high redshift targets. *Right*: Dark Energy Figure of Merit versus the high-z cut-off of an AGN sample. Adding 500 AGN (with a distance modulus uncertainty of 0.2 mag) with $z \leq 3$ to the constraints from SNe Ia, BAO, and CMB increases the total Figure of Merit by a factor 2.